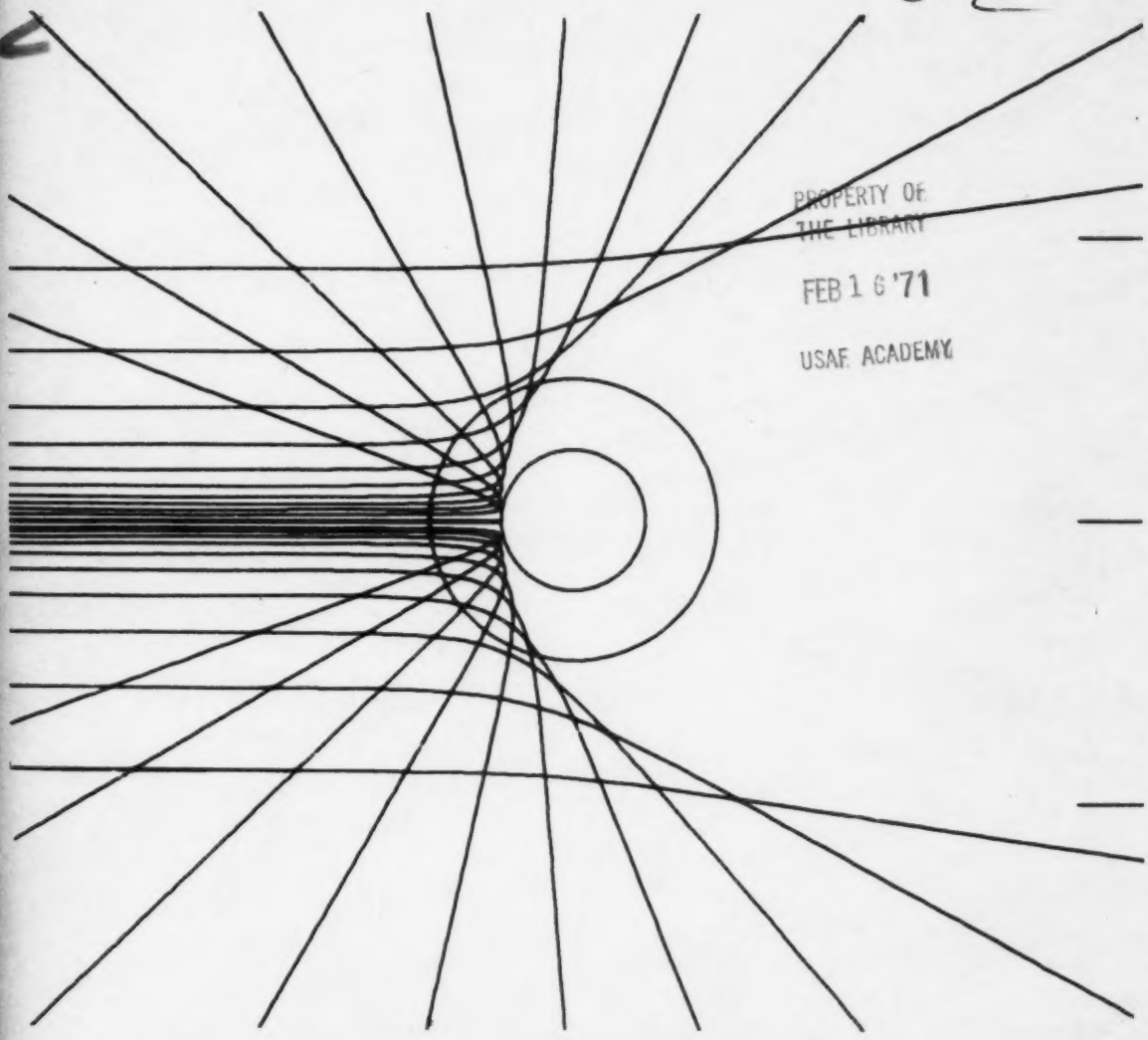
AIR FORCE RESEARCH REVIEW

Number 11

September-October 1970



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AIR FORCE RESEARCH REVIEW

Number 2 **September-October 1970**

ON THE COVER

COMPUTER-GENERATED RAY TRACING: When barium vapor is released by rocket into sunlight at altitudes above 100 km, the barium is ionized by ultraviolet rays to produce a plasma cloud that persists for minutes to hours and reflects radio waves in a characteristic manner. The ray paths of this cloud can be calculated by computer. The computer-generated plot on the cover shows how radio waves are deflected from an ionized cloud. Such clouds can be used as tracers to study natural ionization, as targets for characterizing radar parameters, and as a reflector for over-the-horizon comunications. AFCRL has been a pioneer in this field of research.

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ETHEL GAMER, *Editor*

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electron spectroscopy for the study of semiconductors

DR. D. W. LANGER and CAPTAIN C. J. VESELY

SOLID STATE PHYSICS RESEARCH LABORATORY, ARL

The development of semiconductor devices for Air Force systems depends to a great extent on accurate knowledge of the electronic, optical, photoelectric, and electrooptic properties of solids. Detailed knowledge of electronic energy levels and the electron density of states would help to explain or predict the characteristic differences in properties of various elements and compounds. ARL's Solid State Physics Research Laboratory is currently studying the electronic structure of solids.

Much experimental information already exists on the relative energy positions of the upper valence band and the lower conduction band at several high symmetry points in Si, Ge, and most compounds derived from III-V and II-VI group elements. Our research group must extend the experimental knowledge of the electron energy levels and electron density of states to the lower valence band and core levels. Immediate program results would include:

(1) Experimental data on the actual positions of the bands filled with electrons and the shape of the wider bands, along with the position of energy levels resulting from the addition of various impurity atoms to a host lattice.

(2) New data to allow evaluation of different types of theoretical energy band models and different types of electron exchange approximations.

(3) The shifts in electron core levels of an element, when measured in pure form and when measured in a compound, to help in determining the nature of chemical bonding.

X-ray induced electron emission (IEE) spectroscopy is the technique to be used to pursue these objectives. Varian Associates of Palo Alto, California, has recently developed the first commercial instrument of this type and has sent one of the first units to our research group. Several measurements, already appearing in three publications (1, 2, 3), were made by the authors in Palo Alto on the prototype machine to test the feasibility of using such an instrument for our work.

The operation of an IEE spectrometer is based on the phenomenon of x-ray induced photoemission which has been extensively studied by K. Siegbahn and his co-workers at Uppsala, Sweden (4).

The principles of operation are as follows: $AlK\alpha_{1,2}$ x-rays from an aluminum x-ray anode with an energy of 1486.6 eV and a halfwidth of 1.0 eV interact photoelectrically with electrons in the sample. If the binding energy, W, of the electron is less than the energy of the x-ray, and if all inelastic interactions of the electron after it is excited can be neglected, then the electron is emitted from the sample with a kinetic energy E'_{kin} given by:

$$E'_{kin} = E_{x\text{-}ray} - W$$

Siegbahn demonstrated that indeed a substantial number of electrons are emitted without such inelastic interactions and that the observed kinetic energy spectra can, therefore, be associated with the electronic energy levels.

Figure 1 shows a schematic of the method applied to a semiconductor or insulator. E'_{kin} is the kinetic energy of the emitted electron with respect to the vacuum level of the

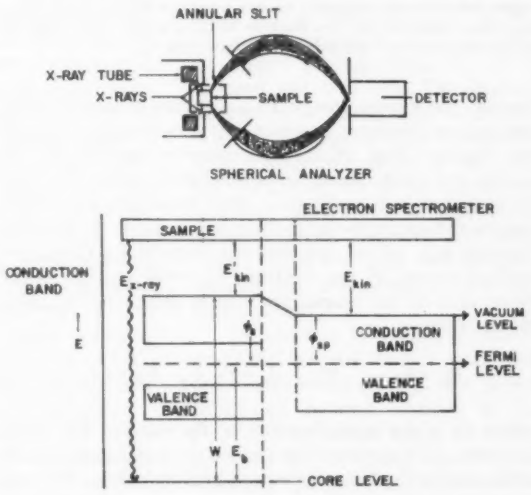

Figure 1. The top section shows a schematic of the instrument. X-rays generated by an annular Al anode strike the sample – which is usually in the shape of a cylinder. The kinetic energy of emitted electrons is analyzed in a spherical electrostatic analyzer. The bottom section shows the energy level diagrams of the spectrometer (metal) and the sample (semiconductor).

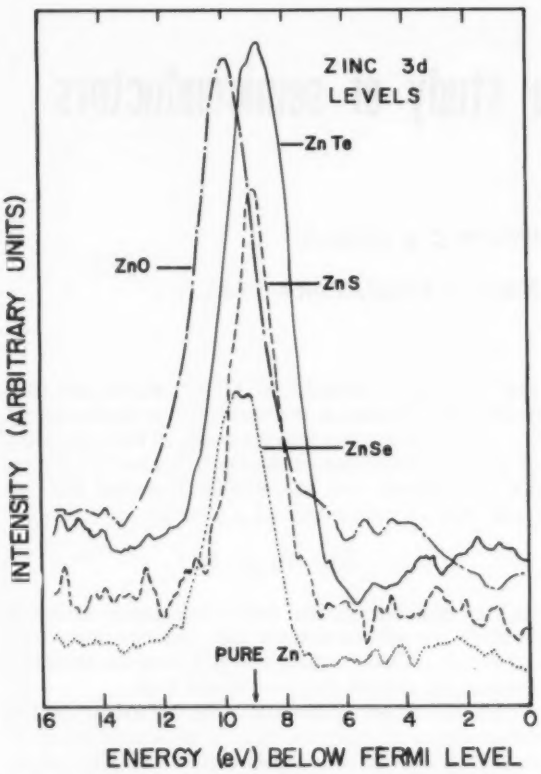

Figure 2. The electron emission spectrum of ZnSe and ZnTe. The upper scale denotes measured kinetic energy of the electrons, E_{kin}; the lower scale denotes the electron binding energy with reference to the Fermi level of the respective compounds, E_b.

sample. The kinetic energy, E_{kin}, actually measured by the electron spectrometer, however, is measured with respect to the vacuum level of the spectrometer material. If the sample and spectrometer are in good electrical contact, and if the system is in equilibrium, then the Fermi level of the sample and spectrometer material will coincide. If the work function ϕ_{sp}, of the spectrometer material is known, the binding energy of the electron, E_b, with respect to the Fermi level of the sample, can then be determined by using the equation,

$$E_b = E_{x\text{-ray}} - E'_{kin} - \phi_s = E_{x\text{-ray}} - E_{kin} - \phi_{sp}$$

where ϕ_s is the work function of the sample. The work function of the spectrometer can be obtained by calibration with respect to a known electron binding energy. We used the carbon 1s level at 283.8 eV for this purpose.

Normal sample preparation consists of taking a single crystal of the material to be examined and crushing it into pieces of about 1 mm^3 volume in order to increase the surface area that is exposed to the x-radiation. The pieces are picked up on a strip of tape which is sticky on both sides and then wrapped around a steel rod and inserted into the sample chamber. Carbon in the tape serves as the reference. Typical spectra are shown in figures 2 and 3.

Figure 2 shows the electron spectrum (1486 eV> E_{kin} > 1386 eV), which corresponds to the electronic energy levels between the Fermi-level and a depth of 100 eV, for ZnTe (solid line) and for ZnSe (dashed line). The dominant peaks are easily identified, with the corresponding atomic core levels as indicated. Many of the smaller peaks are systematic and reproducible, but not yet well enough understood to discuss. The electronic states of the valence bands, composed of the Se 4p and 4s states in ZnSe and of Te 5p and 5s states in ZnTe, are not contributing much to the spectrum, as an inspection of the first 10 to 15 eV shows. This is because their density of states here is relatively small and their coupling to the kilovolt x-rays is relatively weak.

In figure 3, the least bound peak, Zn 3d, is compared with four investigated zinc compounds. The arrow indicates the position of the Zn 3d level in pure zinc if the Fermi levels for the element and compounds are equated. For nearly all compounds, the Zn 3d level has shifted towards higher binding energies, which is symptomatic of an additional positive charge on the zinc atom in the compound, and which the ionic character of the bonding led us to expect.

From data so far obtained from measurements on the prototype device in Palo Alto, we have been able to publish the following results:

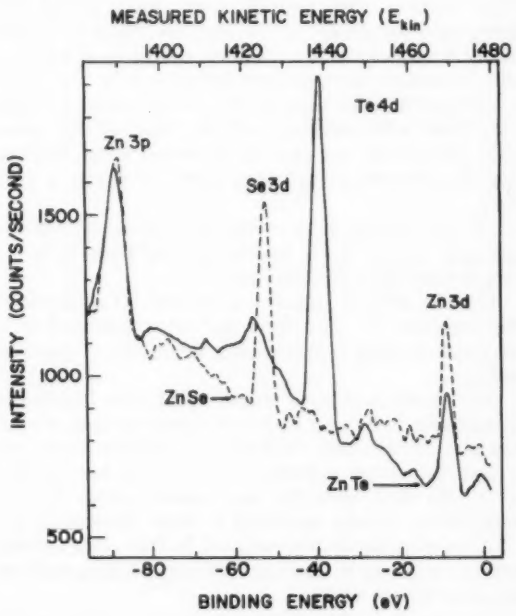

Figure 3. The electron emission spectrum of the zinc chalcogenides in a spectral region that corresponds to electronic states between the Fermi level (E_b = 0 eV) and 16 eV below it. The peaks correspond to the Zn 3d levels in the respective compounds. The arrow indicates the position of the Zn 3d level in Zn metal.

(1) The first experimentally determined values for the electronic core levels down to 1200 eV below the Fermi level were obtained for the zinc chalcogenides (ZnO, ZnS, ZnSe, and ZnTe). Comparison between our data and values predicted by several different types of theoretical calculations indicates a need for an angular momentum-dependent exchange term in the electron exchange approximation.

(2) The location of the Zn 3d level in the zinc chalcogenides was firmly established. The location of this level with respect to the valence band has a large influence on the shape of the valence band structure and, hence, the electronic properties of the respective compounds.

(3) The relative location of electronic levels of some deep luminescence centers, e.g., transition metals or rare earth centers, with respect to the lattice has been accessible to experimental investigation in the past only in those cases where charge transfer could be observed. One system where this was not the case is ZnS:Mn. Our data indicate that the Mn 3d state lies about 3 eV below the top of the ZnS valence band.

(4) The optical density of states of the valence band of Si was determined. Comparison with results obtained by other techniques yielded information that complements the data obtained by the other types of experiment.

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RESILIENCY OF THE EARTH'S CRUST

TERRESTRIAL SCIENCES LABORATORY, AFCRL

The earth, like a rubber ball, is resilient. When force is applied at one place, the surface is depressed and the surrounding area tilts toward the depression. In this way, the earth's crustal layer responds to tidal effects and to changes in atmospheric pressure. During the rainy season when reservoirs fill up, the weight of the water can cause a measurable depression, as can snow and subsurface water movements. Some locations are more susceptible to tilt than others, but no region in the country is entirely free from these tilt effects which can reach 1″ of arc during severe coastal storms.

There are many military reasons why tilt effects should be known with great precision. One reason relates to computer guidance systems aboard missiles in silos: crustal tilt, if unaccounted for, can result in targeting error. Moreover, the tilt properties of a region should be monitored for stability before missile sites are chosen. In the testing of gyros and accelerometers, the orientation of the instrument relative to local vertical or the earth's rotation axis must be known with great accuracy. Geodetic measurements, in which distances between two points of the earth are measured using satellite triangulation techniques, require precise knowledge of the elevation angle of the ground instruments.

In recent years many measurements have been made of crustal tilt, chiefly in Europe, Japan, and the earthquake zones of California. In late February 1970, AFCRL began the installation of an array of tiltmeters to provide the most sensitive measurements of crustal tilt made to date. The three-station system began operating in July. The array is located at L.G. Hanscom Field, Bedford, Mass., near AFCRL's main laboratory complex.

The tiltmeter consists of three detectors arranged in an equilateral triangle measuring about 350 feet on a side, a configuration designed to reduce the effects of local noise. Each tiltmeter was placed in a borehole about 20 meters deep. The elements are placed underground to avoid thermal crustal deformations caused by solar radiation. Built for AFCRL by Arthur D. Little, Inc., the tiltmeters detect tilts as small as 0.001″ of arc. The meters are contained in a cylindrical shaped package about 12 cm in diameter and 1 m long. The detector consists of a diamagnetic mass (carbon) freely suspended in a magnetic field. Change in position of the mass due to crustal tilt is monitored by reflecting light from the suspended carbon element. Two such suspended masses must be used orthogonally, because each is sensitive to tilt in one direction only.

In addition to detecting resilient properties of the earth's crust and inner layers, the array can detect permanent tectonic changes in the earth's crust. Similar arrays have been proposed for detecting possible premonitory changes that may occur before the onset of earthquakes. The experiment was planned and carried out by Gerry H. Cabaniss of AFCRL.

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Determination of the maximum axis temperature in a wall-stabilized electric arc using radial mass inflow*

DR. HERBERT DRUXES and DR. GEORG SCHMITZ
FIRST PHYSICS INSTITUTE OF THE TECHNICAL UNIVERSITY OF AACHEN

and CAPTAIN S. F. GIANNOTTA
THERMOMECHANICS RESEARCH LABORATORY, ARL

Despite its widespread use in engineering applications, the electric arc generally remains only a partially understood phenomenon. Improvements in the operational or design features of arc devices are continually sought and essayed, either to be eventually incorporated or discarded. Arcs are used as high-energy light sources, as welding tools, or as heat sources in wind tunnels. They are also employed to generate high temperature plasma for gas property investigations or for reentry simulation tests.

Typically, the arc may burn along the central axis of a cylindrical tube which is filled with the working gas. In this type of system, the water-cooled chamber walls can tolerate heat fluxes as high as 10 kw/cm^2 which corresponds to a centerline temperature of about 25,000°K. Higher axis temperatures may be reached by injecting gas radially into the arc tube through evenly distributed pores in the wall. This method is called "transpiration cooling"; the "cooling" part refers to the walls. At the same time, the arc becomes constricted and is driven to a higher temperature. This technique also reduces the conductive heat loss to the walls and feeds a sizable portion of the energy radiated to the walls back into the gas stream.

Since the Air Force uses electric arcs as gas heaters in wind tunnel simulation tests for the production of high enthalpy gas streams, Air Force interest in arc technology is oriented toward those research studies which may optimize the design criteria or performance of arc heaters or arc devices.

The purpose of this article is to present a method for calculating the maximum axis temperature attainable in a cylindrically-symmetric, wall-stabilized electric arc with uniform radial mass inflow. The arc parameters, such as the arc voltage, the arc current, and the geometrical configurations, must be known. The variables which uniquely fix the operating limits are: tube radius, wall temperature, the temperature of the coolant, and, in particular, the selected method of introducing the working gas. The heat transfer mechanisms, which transmit arc energy to the cooled walls, must also be considered.

Influence of Different Flows on Electric Arcs

The cascade arc, developed largely by Maecker, produces a stationary thermal arc plasma (without gas flow) which may reach temperatures of several times 10^4°K. Electric field intensities are about 20 volts/cm and currents may range up to several hundred amperes. Cascade arcs are commonly used to determine the plasma transport coefficients as a function of temperature. Ultimately, the electric power input has an upper limit which is set by the maximum thermal wall load. Therefore, it is interesting to consider what type of gaseous flow field might further increase the centerline temperature, holding all other factors constant. Axial or radial flow are the two major flow forms; these may be superposed with an additional azimuthal velocity component. Results of the study of these two main flows by Dr. H. Druxes (1) are summarized as follows:

a. A purely axial flow has no influence on the thermal behaviour of a cylindrically-symmetric arc in the fully developed region; the maximum temperature is the same as for the wall-stabilized cascade arc without flow. (The same is true for a purely azimuthal flow.)

b. A radial flow component complicates the Heller-Elenbaas power balance because of the convectional part of the enthalpy production term, and the thermal behavior of the arc is changed.

Before considering the maximum centerline temperature for radial mass inflow, the arc system and the heat transfer mechanisms will be discussed.

*This research was supported by the Office of Air Research of the West German Defense Ministry under a co-operative agreement with the Thermomechanics Research Laboratory, ARL, which furnished the topic of the study.

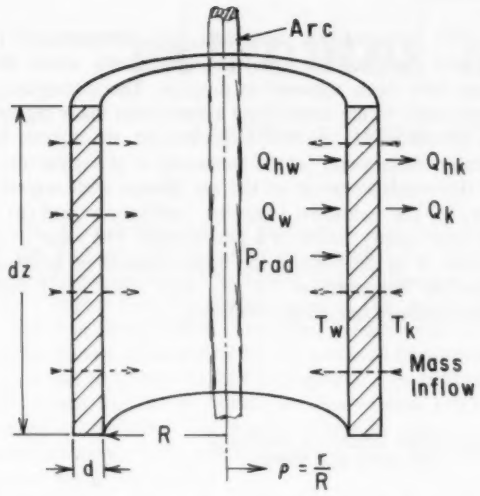

Figure 1. Arc geometry and the power balances.

The Arc Configuration and its Cooling System

Figure 1 illustrates a configuration which is characteristic for many types of arc systems. The cylindrically-symmetric arc burns within a tube of inner radius R and wall thickness d. The outer surface of the tube is held at constant temperature T_k by using a liquid or gaseous coolant. The power input to the arc and the cooling system jointly determine a definite wall temperature T_w. The coolant may penetrate the chamber wall for specific arc-flow designs. Cylindrical coordinates (r, ϕ, z) are used and the radial coordinate is normalized at the inner tube wall ($\rho = r/R$).

Power balances per unit length exist for the arc and the wall. The electric power input to the arc, P_{el}, is conveyed to the wall by heat conduction Q_w, by radiation P_{rad}, and by convection in the radial direction, Q_{hw}. A portion is also expended in changing the arc enthalpy flux in the axial direction d/dz Q_{hz}. In the power balance for the wall, we have the energy absorbed from the arc ($Q_w + P_{rad} + Q_{hw}$) which is transmitted to the coolant by heat conduction Q_k and by convection Q_{hk}. The porosity of the tube wall allows the convectional term.

Temperature Distribution in the Wall

The temperature distribution in the wall is a function which drops monotonically from the temperature at the inner surface, T_w, to the coolant temperature T_k. The inner wall temperature T_w is the maximum temperature of the wall material which is physically reasonable under the restriction that $T_w - T_k$ is smaller than $T_s - T_k$ where T_s is the melting temperature. T_w is uniquely determined by the operating parameters of the arc and by the coolant temperature T_k. To specify the maximum allowable center-line temperature, the wall temperature T_w must first be determined. The reason for this is twofold:

a. The two power balances must match at the inner wall so that a unique (single-valued) wall temperature is specified, and b. T_w must be less than T_s.

The temperature distribution in the wall is obtained by integrating the local power balance of the wall and employing the continuity equation. These two equations are:

$$R\rho_m u \frac{dh}{dr} = \frac{1}{\rho}\frac{d}{d\rho}\left(\rho \kappa \frac{dT}{d\rho}\right) \qquad 1 \leq \rho \leq \left(1 + \frac{d}{R}\right) \qquad (1)$$

$$\rho \rho_m u = \text{constant} = -\dot{m}_r \qquad (2)$$

where u = radial velocity component
κ = thermal conductivity of the gas
h = enthalpy of the gas

The continuity equation has this simple form since no axial component of the velocity vector occurs in the wall. The energy equation also has a simple representation since there is no radiative energy transport through the wall. The boundary conditions are $T_k = T(1 + d/R)$ at the outer tube wall and $q(1) = \frac{-\kappa}{R}\left(\frac{dT}{d\rho}\right)_{\rho = 1}$ at the inner tube wall. Known arc parameters may be substituted for the heat flux q, since q is an integrated value of the energy produced by the arc. The resulting temperature is:

$$T(\rho) - T_k = \frac{P_{el}}{2\pi\bar{\kappa}}\left[1 - 2\pi R \dot{m}_r \frac{h_m - h_w}{P_{el}}\right]\frac{1}{\alpha}\left[\frac{1}{\rho^\alpha} - \frac{1}{(1 + d/R)^\alpha}\right] \qquad (3)$$

where α is the flow parameter (Reynolds number times Prandtl number)

$$\alpha = R \dot{m}_r \frac{\bar{c}_p}{\bar{\kappa}} = R_{ey} \cdot Pr$$

Here $\bar{\kappa}$ is a mean value of the thermal conductivity of the gas, $\bar{c}_p$ is the mean specific heat of the wall material, h_m is the mean enthalpy of the working gas over the arc cross section (of unit length considered), h_w is the enthalpy at the inner tube wall, and $T_w = T(1)$.

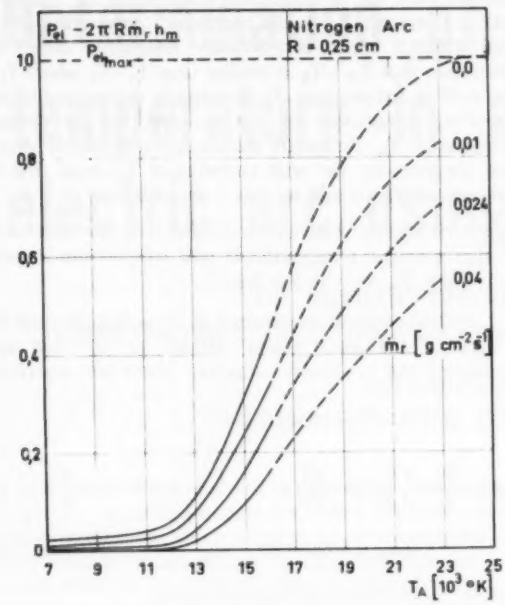

Figure 2. Determination of the maximum axis temperature attainable in arcs with radial mass inflow.

The Maximum Axis Temperature

With the condition $(T_w - T_k) < (T_s - T_k)$, the maximum wall temperature can now be calculated. Dividing both sides of equation 3 by $T_s - T_k$, one finds

$$\frac{T_w - T_k}{T_s - T_k} = \frac{P_{el} - 2\pi R \dot{m}_r h_m}{P_{el_{o\,max}}} \cdot \frac{1 - (1 + \frac{d}{R})^{-a}}{a \ln (1 + \frac{d}{R})} \qquad (4)$$

where $P_{el_{o\,max}} = \frac{2\pi\kappa(T_s - T_k)}{\ln(1 + d/R)}$ = the maximum electric power which can be generated in the arc without radial mass inflow. The wall enthalpy term h_w has been neglected in comparison with h_m. The expression $(P_{el} - 2\pi R \dot{m}_r h_m)$ can be determined as a function of R, T_A and $\dot{m}_r$ by solving the Heller-Elenbaas equation with the (radial) convection term included. Thus, we note the connection between the temperature distribution in the wall and the axis temperature. Selected graphical results are shown in figure 2 where the dashed lines represent one possible extrapolation into regions of unknown transport properties. The ordinate has been normalized by dividing by $P_{el_{o\,max}}$.

Summary

The extrapolated maximum axis temperatures (for different mass inflow rates) lie significantly above those which have been achieved in practice. The discrepancy is attributable to the simplifying assumptions made regarding the operation of any real experimental arc system. Specifically, these were: (a) the laminarity of the radial inflow, (b) the z-independence of the arc plasma with respect to flow, (c) the unknown transport coefficients, and (d) the true (unknown) nature of a porous wall. The value of this analysis is in delineating the upper bounds of achievable centerline temperatures for arcs with radial mass inflow under idealized operating conditions.

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Dr. Herbert Druxes is a research scientist and research group leader at the First Physics Institute of the Technical University of Aachen. He presently conducts investigations of the heating of gas flows in electric arcs. He previously performed experimental work involving shock tubes.

Dr. Druxes received his Master's degree in 1963 and his Ph.D. in 1966, both from the University of Aachen. He has reported on his work at scientific meetings and in published papers.

Dr. Georg Schmitz is a professor at the Technical University of Aachen and is the director of a research group at the First Physics Institute of the University. His current research deals with the theory of electric arcs and the determination of transport coefficients in arc plasmas.

Dr. Schmitz received his Ph.D. from the University of Bonn in 1940. From 1940 to 1945 he worked at the Institute for Aviation Research in Braunschweig. Dr. Schmitz has been associated with the Technical University in Aachen since 1949 and has published numerous scientific papers.

Capt. Salvatore F. Giannotta is a research physicist assigned to the Thermomechanics Research Laboratory, ARL. He is currently studying plasma-magnetic field interactions involving high and low density plasmas.

Capt. Giannotta received his M.S. degree in Physics from the Air Force Institute of Technology in 1966. He continued his studies in physics at the Ohio State University from 1966 to 1969.

extremes of hot weather

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

El-Azizia, Libya, has one distinction. It is the location of the highest temperature ever recorded by standard meteorological instruments–136°F. But this temperature is only 2° higher than the highest recorded U.S. temperature of 134°F in Death Valley. Araouane, French Sudan, in the western Sahara holds the record for sustained high temperature; it has temperatures 120°F or greater 1 percent of the time during its hottest month, and higher than 110°F 10 percent of the time. The hottest extended region of the world stretches from northern Africa eastward through most of India.

These are some of the facts presented in "World Frequency of High Temperature" (*AFCRL-69-0348*), an AFCRL report prepared by Paul I. Tattelman, Norman Sissenwine, and Robert W. Lenhard, Jr. The study was made for the forthcoming revision of Military Standard 210A, "Climatic Extremes for Military Equipment," the DOD document used by designers of military equipment as a specifications reference. Mr. Sissenwine provided climatological data for the original MIL-STD-210 in 1951.

The AFCRL study covers 450 locations all over the world, selected for their high temperatures. For each location, an index was developed based on temperatures recorded during its warmest month. The index is derived from the mean daily maximum and the mean daily minimum temperatures.

The report also discusses temperatures in familiar Fahrenheit terms. For example, temperatures above 85° will be registered 10 percent of the time in Boston during July, and will be above 94° 1 percent of the time. In Phoenix, the hottest large U.S. city, July temperatures above 104° will be recorded 10 percent of the time.

Although the interiors of Australia and South America are two of the world's important high temperature regions, neither reaches temperatures of 110° for more than a few hours each month. Elsewhere, sustained temperatures are higher. Temperatures above 115° are reached at least 5 percent of the time in parts of northern Africa, Iraq, and Death Valley, California.

To make comparison easy, the AFCRL report plots isolines of high temperature regions on maps. The report complements an AFCRL report issued in 1968 on the duration of extremely cold temperatures over North America. Whereas the hottest temperature ever recorded was 136° at El-Azizia, the 1968 report shows that the coldest recorded temperature over North America was -80°F at Snag, Yukon Territory near the Alaskan border. A sister report is now being prepared on the probability of cold temperatures over the Northern Hemisphere.

Norman Sissenwine (left) and Robert Lenhard have recently completed a study on the extremes of hot climate at various geographical locations. The study will aid designers of military equipment which must operate in regions of the world where temperatures are extreme.

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Mr. Sissenwine's biography appears in the OAR Research Review, Vol. VIII No. 3, May-June 1969, p. 8.

Mr. Robert W. Lenhard, Jr. joined AFCRL in May 1965 as a retired Lt Colonel of USAF where he had totaled 16 years of experience as a meteorologist. At present he is a research meteorologist in the Design Climatology Branch of the Aerospace Instrumentation Laboratory where he is studying time and space variations of wind, with special emphasis on fine-scale winds and turbulence in the troposphere, stratosphere, and lower mesosphere. The objective in these wind measurements is to obtain a climatology applicable to problems in designing missiles and aerospace vehicles.

Mr. Lenhard received his B.S. in Meteorology in 1944 from the University of Chicago and his M.S. in the same subject from Florida State University in 1953. He is a member of the American Meteorological Society and the Royal Meteorological Society.

Electrochemical and Biological Oscillators

ROBERT DE LEVIE

DEPARTMENT OF CHEMISTRY, GEORGETOWN UNIVERSITY

The connection between electrochemical and biological phenomena is as old as the study of electricity: Galvani used the muscle contraction of frog legs as the first detector of electrical currents. Oscillatory behavior of electrochemical systems was observed around 1830 and was studied by Faraday, among others. At the turn of the century, Ostwald noticed the striking similarity between signal transmission in nerves and the transmission of passivation along iron wires, an analogy further demonstrated in great detail by Lillie.

Information is transported in the nervous system via pulse trains; their frequencies code the information carried. The mechanism of pulse transmission along the nerve is understood, at least in a formal sense, through the work of Hodgkin and Huxley (1), but the processes by which external or brain and spine commands are coded and decoded are still quite obscure. The coding apparently involves the translation of a chemical signal, via an intermediary "receptor potential," into a sequence of electrochemical pulses, a process termed "electrogenesis."

During studies of electrochemical kinetics, sponsored by the Air Force Office of Scientific Research, our research group at Georgetown University came across the peculiar phenomenon of negative resistance (2). Such a negative resistance is observed when the rate of an electrode reduction, over a given range of potentials, decreases as the potential is made more negative and hence more reducing. Such unusual behavior can be caused by increasing coulombic repulsion of anions which are being reduced, or by similar repulsion of anions which catalyze the electroreduction of cations. The latter is the case in the reduction of trivalent indium ions from aqueous thiocyanate solutions, a reduction catalyzed by thiocyanate anions adsorbed on the electrode.

Mathematical analysis (3) of the interplay between the rate of the electrode reaction itself and that of the transport (diffusion) of reducible ions to the electrode leads to the conclusion that both processes are intimately connected. Such coupling is not surprising, since the rate at which material is transported must be governed by the rate at which it is consumed at the electrode. This coupling has the interesting property of generating an additional negative diffusion capacitance when the electrode reaction exhibits a negative resistance. Such negative capacitances (2, 3) have indeed been observed.

The combination of negative electrochemical resistances and capacitances, together with the usual positive resistances and capacitances found abundantly in both electrochemical and biochemical systems, supplies all the necessary ingredients for oscillatory behavior. A negative resistance alone can make the system unstable, since it can compensate for energy loss (heat dissipation, the electrical analogue of mechanical friction) in un-

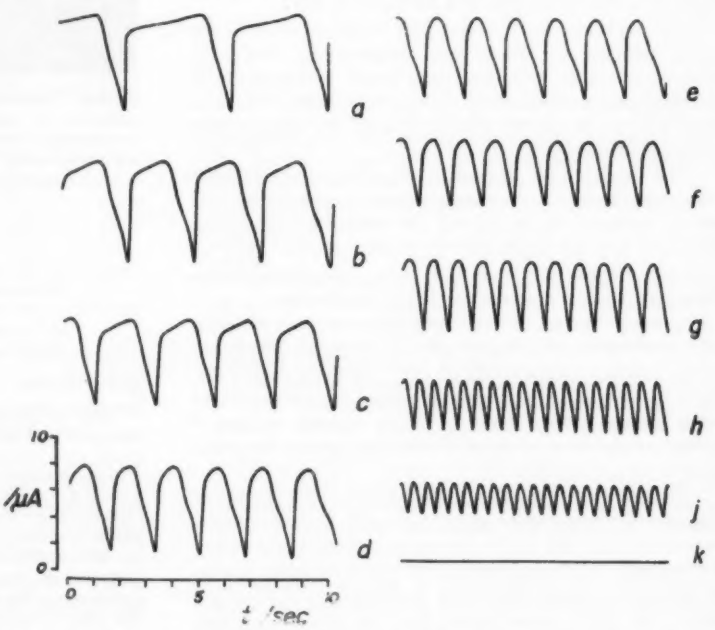

Figure 1. Steady-state oscillations observed on a single hanging mercury droplet in a 1.2 mM $In(NO_3)_3$, 6 M NaSCN solution, pH 3.6. Potentials applied via 51 KΩ; reference electrode Ag/AgSCN. Potentials in volts: a = -0.99; b = -0.98; c = -0.97; d = -0.95; e = -0.93; f = -0.89; g = -0.85; h = -0.74; j = -0.72; k = -0.71.

avoidable positive resistances. However, for oscillatory behavior, instability is not enough; the energy must also be shifted back and forth between two "containers" in which it can be stored alternately.

In an inductance-capacitance (L-C) oscillator, for example, the energy is stored alternately in the electric field of the capacitor C and in the magnetic field of the inductor L, while an electronic device (vacuum tube or transistor) provides the negative resistance. No oscillation results when either the capacitance or the inductance is omitted, illustrating that a negative resistance alone is insufficient to sustain a continuous oscillation.

The following mechanical analogue may illustrate the difference between instability and oscillatory behavior. An unsuspended weight is unstable; it will fall down, converting potential energy into kinetic energy until it hits the floor. A weight suspended from an off-balance, frictionless pendulum will also be unstable, but its downward motion will be oscillatory since it can convert potential energy back and forth into kinetic energy.

From the above discussion, one would predict that electrochemical oscillators can be constructed, based on the negative resistance of a heterogeneous (surface) reaction like the thiocyanate-catalyzed reduction of indium, and the coupling of diffusion and reduction processes. Indeed, such oscillators are readily observed (4). Needed only is an external source of constant voltage and a resistor plus two electrodes immersed in a solution containing both indium and thiocyanate ions. The usual properties of the electrode-solution interface supply the necessary positive capacitance. The resulting oscillations (see figure 1) bear a striking resemblance to those found in the nervous system. The oscillations can be turned on and off, and their frequencies can be changed by varying the applied potential. In biological systems, redox potentials [like the so-called "early receptor potentials" observed upon optical stimulation of vertebrate eyes (5)] take the place of externally applied voltages. Thus it appears that we have here at least a chemical model for electrogenesis, based on a heterogeneous (surface) reaction and its coupling with diffusion transport of the reactants.

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Atmospheric Aerosols, Stratospheric Dust, and Twilight Colors

OPTICAL PHYSICS LABORATORY, AFCRL

Exhaust products from automobiles and aircraft, burning dumps, and industrial and home furnaces make up only a minor portion of the atmospheric aerosols on a global scale. Most aerosols have natural sources such as ammonium sulphate particles, dust, and salt particles from evaporated ocean spray.

Atmospheric aerosol studies, although of long range interest to environmentalists, are of more immediate interest to the Air Force. The gathered data, which are essential to the designers of airborne and satellite optical reconnaissance and surveillance instruments, define the operational capabilities and limitations of the instruments after they are placed in operation.

Studies conducted by Dr. Frederic E. Volz, AFCRL, indicate surprisingly little variation in aerosol size and in aerosol distribution by geographic regions. Marked daily variations in aerosol conditions may exist at a given location, but the pattern of variations observed in the atmosphere is much the same whether in New England, Yugoslavia, Sweden, or California. The biggest difference appears between the aerosol concentrations over land and those over oceans, but quantitative data are lacking on these differences.

The main problem faced by Dr. Volz is the establishment of a "normal" baseline condition for the monitoring of worldwide increases in atmospheric aerosols resulting from man's activity. To derive such a scale for plotting long term trends, many observations over a long period are needed.

Size distribution of aerosols can be inferred from photometric measurements of skylight intensities at various angles from the sun and of spectral attenuation of solar radiation. Even without instrumentation, the effects of size distribution of atmospheric aerosols are readily observable in the changes in the hues of the sky and the colors of the sunset. A high concentration of relatively small aerosol

particles will produce a deep red sunset, while a mixture of particle sizes will produce a hazy white sunset.

The most recent measurements conducted by Dr. Volz show that particles over tropical maritime regions (which are probably largely salt particles) are more uniform and relatively larger than those over the continental regions. Because aerosols can be transported over great distances, day-to-day variations in aerosol size distribution may occur at a given location. An example was the dust from a Sahara windstorm which was transported across the ocean to form an unusually large aerosol layer above the sea salt haze of the Carribean.

The volcanic dust from the Krakatoa volcano in Indonesia, which erupted in 1883, treated the world to spectacular twilights for two years. The horizon, soon after sunset, lit up in brilliant colors that filled the whole sky, at times lasting as long as 90 minutes. The volcanic dust, transported to the stratosphere, formed a persistent layer at altitudes between 18 and 30 km. In a paper presented in April at the meeting of the Optical Society of America in Philadelphia, Dr. Volz reexamined the Krakatoa eruption and other events as a contextual framework for his more recent twilight observations. Writings in 1883 and 1884 on the variety of twilight colors following the Krakatoa eruption have been used to infer the wind circulation in the stratosphere and the rate of mixing and diffusion of volcanic dust. The stratosphere, unlike the more turbulent troposphere, is relatively stable; dust trapped in this atmospheric layer tends to persist for long periods.

Since 1884, few volcanic eruptions have produced twilights of such widespread geographic extent, variety, and intensity. The volcanic eruption in 1963 at Agung, Bali, came closest. It was largely confined to southern latitudes where, for more than a year, the stratospheric dust reduced the solar radiation reaching the earth by as much as 15 percent. Although stratospheric dust increased ninefold in the northern mid-latitudes, few persons noticed that twilights were longer and somewhat brighter.

Since 1959, Dr. Volz has attempted, with precisely calibrated photometers at several locations, to obtain objective standardized twilight measurements to accumulate data on concentrations of dust in the stratosphere on a long term continuing basis. During the past five years, cooperating volunteers at latitudes from northern Canada to Chile have provided twilight photographs taken with infrared film. Procedures called for making exposures during cloudless periods when the sun is about 4 degrees below the horizon; the most intense twilight is then found at an elevation of about 20 degrees. Photometric measurements indicate that the worldwide twilight radiance, relatively low before 1963, increased significantly after the Agung eruption and, replenished by several later volcanic eruptions, has been sustained at a relatively high level.

Dr. Frederic E. Volz examines a photometer of the type he uses in his studies of atmospheric aerosols.

Contact: Dr. Frederich E. Volz
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Dr. Frederick E. Volz is a research physicist in the Optical Physics Laboratory of AFCRL. Since 1967, Dr. Volz has been studying the stratospheric dust layers by measuring and evaluating twilight sky radiation and sky polarization and also has studied the occurrence of stratospheric dust clouds. He has investigated atmospheric transmission in the visible and near infrared spectral range and distribution of daytime sky radiance at tropical latitudes.

Dr. Volz received his Dipl. Phys. (Physics) in 1950, and his Ph.D. in 1954, both from the University of Frankfurt/Main, West Germany.

Before coming to AFCRL, Dr. Volz was a research physicist at the University of Tuebingen (1962-1967), W. Germany; Harvard University (1958-1962), Cambridge, Mass.; and the University of Mainz (1952-1958), W. Germany.

He has authored over 48 scientific publications and is a member of the Deutsche Meteorologische Gesellschaft, the American Meteorological Society, and the Optical Society of America.

New Power Transistors With High Radiation Tolerance

BOBBY L. BUCHANAN

SOLID STATE SCIENCES LABORATORY, AFCRL

An atomic explosion releases a dense flux of neutrons, x-rays and electrons; this radiation can knock out missile guidance and other airborne or ground electronics systems at ranges much greater than those that would cause structural damage. Vulnerability to this radiation damage can be reduced for circuits, such as memory, with redundant components or with protection circuits that cut off critical components during the initial radiation transient. A more direct approach is to build radiation tolerance, or hardness, into the devices themselves.

With this direct approach, AFCRL has obtained some outstanding results. Extensive tests in each of the pertinent nuclear radiation environments demonstrated that the devices developed by AFCRL satisfied military specifications at radiation levels 10 times those at which the best commercially available devices fail.

The three principal categories of radiation damage to transistors are displacement, ionization, and thermomechanical. The main cause of displacement damage is fast neutrons, and the main effects which permanently degrade transistor operation are minority carrier lifetime reduction and carrier removal. A second order effect is mobility reduction. The main cause of ionization damage is gamma radiation which induces permanent effects due to charge buildup in the oxide and transient effects caused by photo-current generation. The transient effects are usually handled by using circumvention techniques in the electronics system. The extent of the transistor degradation due to displacement and ionization damage depends strongly on the transistor type, whereas the extent of thermomechanical damage depends mainly on packaging and metallization which are common to all transistor types.

The power bipolar transistor is one of a number of semiconductor devices that have been radiation-hardened by AFCRL. The approach has effectively been one of determining and putting radiation effects parameters into the design equations of semiconductor devices and designing to minimize radiation induced changes in electrical parameters—very similar to the approach that has always been taken in minimizing undesirable changes due to temperature fluctuations.

The high radiation tolerance of the power bipolar transistor was achieved, not through radical design concepts or the use of special semiconductor materials or dopants, but through the perfection of more or less standard techniques dictated by the design equations. Each power device effectively consists of an array of silicon power transistors connected in parallel. The most significant design feature is in the thickness of the silicon base; the base layer is only about one-half micron thick. Fabrication of extremely thin layered devices, however, poses the problem of an excessively high rejection rate—or low yield. This is especially true for high power transistors because of the additional requirement of a relatively large area.

Curiously, manufacturers are moving in the direction of thinner semiconductor layers, but for reasons other than radiation hardening. Since faster switching speeds of data processing circuits are achieved with thinner semiconductor layers, the requirements for speed and radiation resistance become the same. These high speed devices do not have the requirement of the thin layers being uniform over a large area—which power transistors must have since they do not have a high power requirement.

Contact: Mr. Bobby L. Buchanan
Telephone Ext. 2207

Mr. Bobby L. Buchanan has been a research physicist in the Device Physics Branch of AFCRL's Solid State Sciences Laboratory since 1959. He plans and conducts research in new device concepts and in radiation resistance to extend the state-of-the-art of ultra-reliable low power device design and to increase understanding of the effect of ionizing radiation on the performance of such devices.

In June 1953 Mr. Buchanan received his B.S. in Mathematics and Physics from Western Kentucky State College. The following year, under the USAFIT program, he studied applied mathematics at Harvard, and in June 1959 he received an M.S. in Mathematics and Physics from the Northeastern University.

From July 1954 to July 1957, Mr. Buchanan was a research mathematician in the Communications Laboratory of AFCRC. The next two years were spent in AFCRL's Communication Sciences Laboratory in the field of statistical communication theory. He is a member of RESA.

Gamma Radiation Energy Absorption At Material Interfaces

JAMES A. WALL and EDWARD A. BURKE

SOLID STATE SCIENCES LABORATORY, AFCRL

The determination of the effects of nuclear radiation on semiconductor electronic devices requires accurate knowledge of the energy deposited by the radiation (the dose) in the active region of the device. To date, the method used for measuring the dose has been to expose a radiation dosimeter to the same irradiation environment as the device. Then it was assumed that the device received the dose indicated by the dosimeter, with minor corrections to account for any differences in radiation energy absorption characteristics between the device and the dosimeter. Recent experiments at AFCRL on the dose distribution at and near the interface of two materials of different atomic number have shown that this procedure may lead to large errors in determining the dose received by the active region of a device.

By exposing a multiple plate ionization chamber consisting of closely spaced thin foils to the AFCRL cobalt-60 source and mounting end plates of different atomic number to the chamber, the dose distribution in the chamber has been found to differ considerably from that expected from present theoretical calculations or dosimetric measurements. For example, using an all-aluminum multiple ionization chamber with a gold plate at one end, the dose near the gold was found to be almost twice as high as it would be if the gold were replaced by aluminum. This effect was detected with the radiation directed from the aluminum toward the gold. The increase in dose was observable at significant depths (about 1000 microns) in the aluminum, falling roughly exponentially with distance away from the gold. When the radiation was directed from the gold toward the aluminum, the dose at the gold-aluminum interface was about 50% higher than for an all-aluminum chamber, but at a distance of about 20 microns from the gold-aluminum boundary, the dose fell quickly to a value 10% below the dose for an all-aluminum chamber. Beyond this point the dose rose slowly to the all-aluminum chamber value. Tests with other metals of higher atomic number than aluminum produced similar results of lower magnitude.

When beryllium was used in conjunction with the aluminum chamber, the dose in the aluminum increased

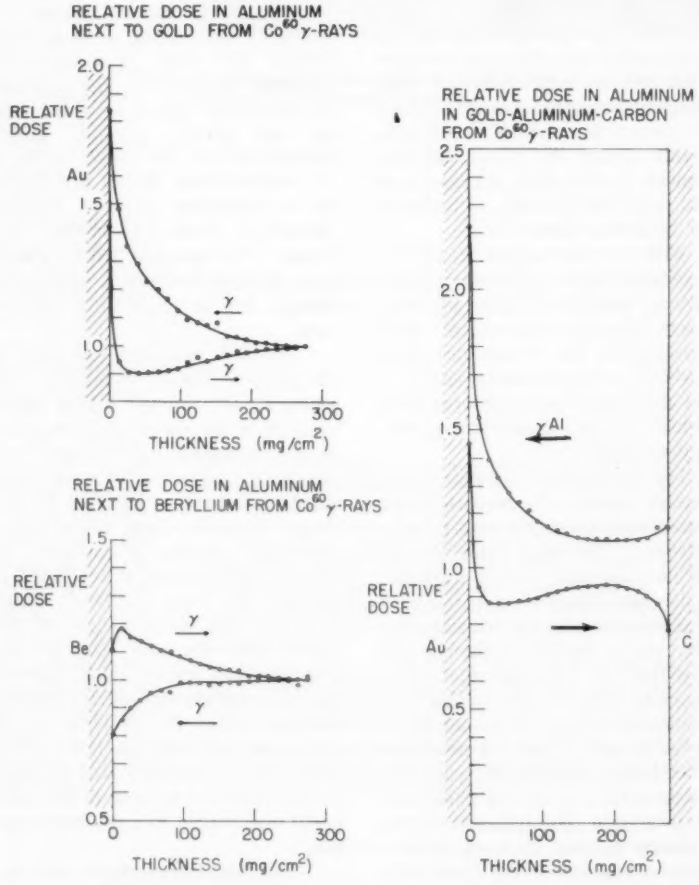

Figure 1. The effects of high and low atomic number materials on the dose in aluminum and their combined effect on an aluminum layer one half the thickness of a Compton electron range.

20% at a distance of 5 microns from the beryllium-aluminum boundary when the radiation was directed from the beryllium toward the aluminum. When the radiation was directed from the aluminum toward the beryllium, the dose dropped 20% at the aluminum-beryllium interface. Similar results were noted when beryllium was replaced by carbon. Thus, placing material of low atomic number in front of one of higher atomic number can increase the dose to the higher atomic number material, a result completely unexpected from current theoretical dosimetry. Plots of the experimental data for these results are shown in figure 1.

The implications of these results, in relation to semiconductor device radiation effects testing, are evident. Many contemporary semiconductor devices consist of a silicon chip with active regions within the range of these spatially dependent reported effects. Gold plating on the surface, high-atomic-number metal contacts, a support for the chip, and an enclosure provide the interfaces which can cause large variations in dose through the active region of the device. Since aluminum and silicon have nearly identical radiation absorption characteristics, the effects described are directly applicable to silicon devices. The determination of radiation effects on semiconductor devices has a long history of inconsistent results from different testing facilities and device types. These inconsistencies may be at least in part attributable to the effects described here.

It is expected that the AFCRL experiments on the dose distribution at interfaces will lead to theoretical results from which the observed effects can be calculated and taken into account in radiation effects studies. Meanwhile, current dosimetric procedures must be carefully evaluated to determine their validity in any given radiation effects experiment.

Contact: Mr. James A. Wall
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Since 1966, Mr. James A. Wall has been a research physicist in the Radiation Effects Branch of AFCRL's Solid State Sciences Laboratory where he has pursued research in radiation effects and dosimetry. Presently, Mr. Wall is engaged in a project to determine the low-energy secondary electron emission produced by high-energy electron and gamma radiation incident on metals and insulators.

Mr. Wall received a B.S. in Physics in 1954 from the Massachusetts Institute of Technology and an M.S. in Mathematics and Physics in 1958 from the Northeastern University. While employed at Tracerlab, Inc., Waltham, Mass. (1955-1958), he was concerned with low level radioactivity analysis and heavy element mass spectrometry. Thereafter, his experience included radiation detector development, activation analysis, dosimetry, and the AFCRL linear electron accelerator.

Mr. Wall has regularly published articles on his work and was granted a patent in June 1962 on "Radiation Detection Apparatus."

Mr. Edward A. Burke has been a research chemist in the Radiation Effects Branch of AFCRL's Solid State Sciences Laboratory since 1957. His work on radiation effects and radiation dosimetry has resulted in methods for predicting charge emission from irradiated solids, a revision in atomic cascade models used in radiation damage calculations, determination of threshold energies for atomic displacement, and new measurement methods for low-energy x-ray and neutron spectra. He is currently engaged in low-temperature electron bombardment studies of solids and the determination of secondary electron emission for application to irradiated electronic devices.

Mr. Burke was the recipient in 1950 of a B.S. in Chemical Engineering from the Northeastern University. He has also completed the AEC-sponsored graduate course in Radiological Physics at the University of Rochester. Mr. Burke is a member of the American Physical Society, the Health Physics Society, and the Research Society of America. He regularly publishes or presents papers on his research results.

James A. Wall (left) and Edward A. Burke examine the experimental setup used to evaluate gamma radiation absorption in semiconductor materials.

High Resolution From Small Antennas By Signal Processing

MICROWAVE PHYSICS LABORATORY, AFCRL

If you want better resolution from an antenna, one solution is to build it bigger. Another way is to enhance the detail by mathematically processing the signal with computers and thus elevate the performance of a small antenna to that of a larger one.

New procedures recently tested by AFCRL for enhancing antenna images have produced dramatic results. The procedures, which emerged from AFCRL's work in coherence theory, were formulated by Dr. Allan C. Schell and Major Frederick H. Cleveland; the procedures offer several advantages over other image enhancement schemes. Unlike the others, the enhancement processing does not degrade rapidly in the presence of noise. Nor does it produce the physically impossible results which sometimes appear when the computer carries a problem through conventional extrapolation.

The AFCRL method has been adapted for use with the 29-foot millimeter wave antenna at Prospect Hill in Waltham, Mass. The effectiveness of the new method was demonstrated in recent comparison tests with the 120-foot diameter Haystack antenna operated by Lincoln Laboratory. Both antennas, operating at 8 mm, simultaneously scanned the disc of the sun to produce a cross section profile of temperature variations at a given solar latitude. By scanning across other latitudes, a complete temperature map was constructed. The AFCRL antenna, with enhancement processing, yielded a solar map that compared well with the map from the much larger Haystack antenna.

Dr. Allen C. Schell (left) and Major Fred H. Cleveland study line scans of the sun. The contours of these lines depict variations in temperatures over the solar surface.

Unlike other enhancement schemes, the AFCRL method does not depend on the extrapolation of frequencies beyond those detected by the antenna. The AFCRL method is a two-step process, involving Fourier transformation and the computer solution to an integral equation. The first step is to restore the spectral components of the source that the antenna, acting as a low-pass filter, has altered. This process is equivalent to the equalization of filters in network theory.

After the spectral components are restored, the second step is to retrieve and sharpen detail. The mathematical process is one of fitting, by the least-mean-square error process, a finite range autocorrelation function to the spectral components of the principal solution. The answers obtained by the computer are thereby non-negative answers, representing physically possible source distributions.

AFCRL has applied the enhancement technique exclusively for observing temperature variations over the solar disc, but can also use it for more general applications.

Contact: Dr. Allan C. Schell
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or
Major Frederick H. Cleveland
Telephone Ext. 3764

Dr. Allan Carter Schell has been a research physicist at AFCRL's Microwave Physics Laboratory since July 1956. Here he conducts projects concerning antenna analysis, including angular resolution enhancement, pattern synthesis, reflector arrays, and signal processing.

After receiving his M.S. in Electrical Engineering in June 1956 from the Massachusetts Institute of Technology as a National Science Foundation Fellow, he spent a year studying in the Department of Electrical Engineering of the Technical University of Delft, Holland, on a Fulbright Award. In 1961 he received an Sc.D. from M.I.T., under a Joint National Science Foundation–USAF Fellowship.

Dr. Schell received the Honorable Mention, Marcus O'Day Award in 1964 for the best published AFCRL paper and the Guenter Loeser Memorial Award in 1965. He is a member of the I.E.E.E., Tau Beta Pi, Sigma Xi, and the Scientific Research Society of America. He has lectured extensively on antenna theory and has been a member since 1965 of the Institute for Defense Analysis Panel on "Radar Technology for Defender."

Major Frederick H. Cleveland has been an electronics engineer in the Radiation and Reflection Branch of AFCRL's Microwave Physics Laboratory since 1966 where he is engaged in the design, fabrication, and testing of new type antennas, transmission lines, and signal processing. He is particularly concerned with developing techniques for synthesizing antenna patterns and designing quasi-optical transmission lines at 140 GHz.

Major Cleveland is a member of I.E.E.E., Eta Kappa Nu, Tau Beta Pi, Phi Kappa Phi, and Sigma Xi.

Keeping Balloons On Station

AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

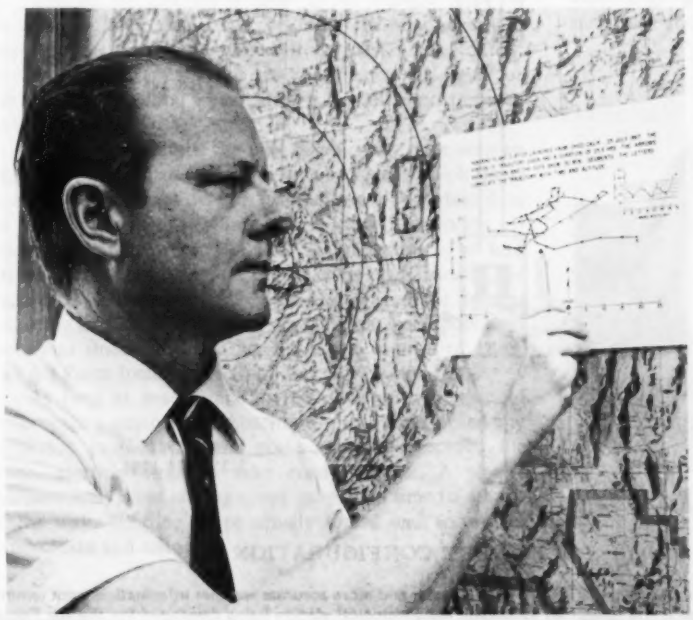
Tethered balloons have a long military history; they were first used in 1794 by the French army for battlefield observations. During the Civil War and World War I, they were used for the same purpose. Tethered balloons still offer advantages in military surveillance; they carry instruments instead of men, and can also be used as radio relay stations and as platforms for scientific instruments. Captive balloons can be sent to altitudes of 10,000 feet without difficulty and AFCRL believes it possible to suspend balloons on a tether at altitudes as high as 100,000 feet.

To maintain a balloon on station at altitudes above 50,000 feet, it is probably simpler to release the balloon in free flight. Then, by dropping ballast or valving gas, it is possible, when it wanders too far, to adjust its altitude up or down in search of winds that will carry it back toward the station. Because high alititude winds change direction with altitude, the balloon can be maintained for a day or so within a 20-mile radius of the ground station until the ballast runs out or valving causes loss of buoyancy. AFCRL has conducted such tests from its Chico, California, balloon launch site.

To evaluate the operational feasibility of a station-keeping free balloon, the characteristic wind patterns as a function of altitude during a given season at a given geographical location must be known. For tethered balloon operation at lower altitudes, knowledge of characteristic winds is also required, but even more important is knowing the probabilities of winds exceeding certain velocities at a given altitude. When wind velocities are too high, tethered balloons cannot be deployed. To evaluate the operational feasibility of tethered balloons up to altitudes of 10,000 feet or more, a set of probability tables of wind speeds at certain locations is needed.

George F. Nolan of AFCRL has recently formulated such tables for both the free and tethered balloons. He points out, that the existence of a combination of westerlies and easterlies with a light wind layer between is the ideal wind situation for free hovering balloons. This combination is found at about 60,000 to 65,000 feet during the summer over a large area of the world and usually all the year round in the tropics.

For tethered balloons, the probabilities of excessive winds as a function of season and location must be known for both operational and design reasons. For example, if the operational requirement calls for a tethered balloon that will remain aloft for 10 hours with a 60 percent chance of completing its mission, the designer first consults velocity probabilities of the type discussed here. He then determines the cable strength, balloon size, and balloon shape for meeting the operational requirement.



Free balloons can be confined to a narrow geographical region by changing the balloon's altitude in a serach for winds that will bring it back to station when it drifts too far. Here George F. Nolan traces the path of one AFCRL balloon maintained on station by this procedure.

Contact: Mr. George F. Nolan
Telephone Ext. 3008

Since 1963, Mr. George F. Nolan has been a research meteorologist in AFCRL's Aerospace Instrumentation Laboratory. He is the principal scientist for the Laboratory's balloon flight operations research, and is currently the field test director for balloon research test programs. He is responsible for originating and developing short and long range research objectives in the areas of atmospheric influences on balloon behavior and in applications of balloons to meet Air Force mission requirements.

Mr. Nolan received a B.S. in Mathematics and Science in 1952 from State College in Bridgewater, Mass., and an M.S. in Meteorology in 1959 from the Massachusetts Institute of Technology. Before joining AFCRL as a civilian, he was chief meteorologist on Project BANSHEE at the White Sands Missile Range and on Project Stargazer, the USAF manned balloon astronomy program.

Mr. Nolan has authored various publications on balloon research, and is a member of the American Meteorological Society.

Expendable, Air-Dropped Remote Weather Station

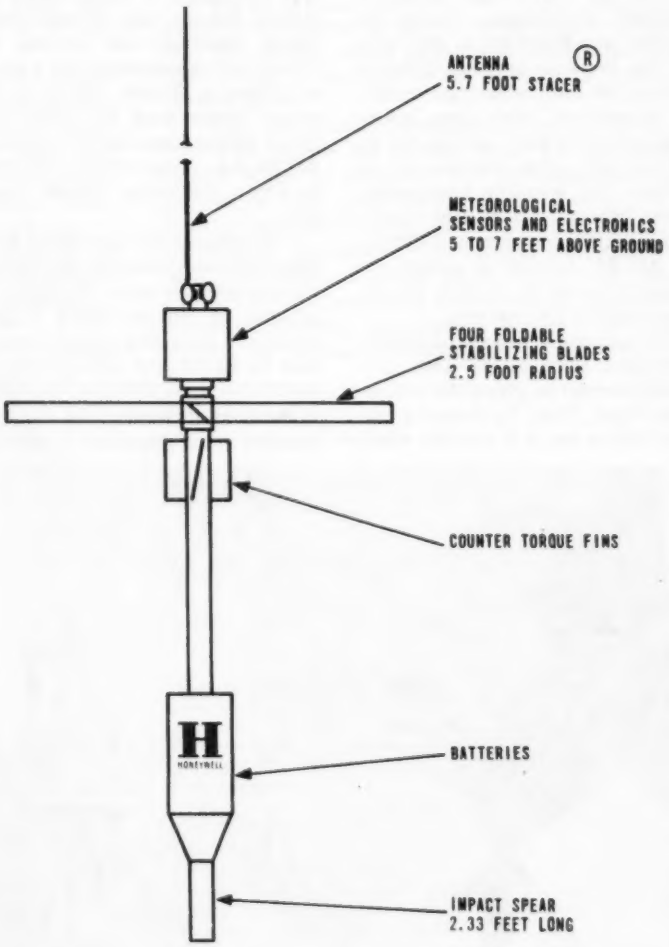
AEROSPACE INSTRUMENTATION LABORATORY, AFCRL

AFCRL has awarded a $320,000 contract to Honeywell's Aerospace Division in St. Petersburg, Florida, for the development of an expendable weather station for the Air Weather Service. The station is to be air-dropped in remote, inaccessible areas.

Designated EROWS (Expendable Remote Operation Weather Station), the weather station looks like a large arrow. It is cylindrical, about 8 feet long and 6 inches in diameter, and weighs 55 pounds. When dropped from the aircraft, it is stabilized and descends to the ground on four rotating blades, each 2.5 feet long. A spear-like tip imbeds itself into the ground and a 5.7 foot vertical dipole antenna is automatically raised into position.

The 4-pound sensor package, located near the top, measures wind speed and direction, atmospheric pressure, temperature, humidity, precipitation, and cloud cover. Data gathered by the station are transmitted to a master control through FM telemetry equipment. The battery-operated station is designed to operate for at least 10 days. One master station will be able to handle data from 34 remote stations. The master unit will include an interrogation module to display the exact status of the EROWS being interrogated. Remote checkout of the EROWS can also be accomplished from the master unit.

Cost of each of the EROWS units, once they are fully developed and ready for production, is estimated to be about $1000; but this figure could vary greatly, depending on the quantities produced.



EROWS PRELIMINARY CONFIGURATION

Figure 1. WEATHER OR NOT—Faster and more accurate weather information from remote areas is the aim of an automatic meteorological station being developed for the Air Force. The air-delivered device, shown here in an artist's concept, is designed to implant itself in the ground on a spear-like tip to sample weather information such as wind speed and direction, atomospheric pressure, temperature, humidity, precipitation, and cloud cover and to report its data to a receiver station.

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Global Hazards For Flight Safety Are Expanding*

CHARLES E. FULLER, LT. COL, USAF, VC

DIRECTORATE OF LIFE SCIENCES, AFOSR

The U.S. Air Force is now suffering losses of more than $10 million a year because of bird/aircraft collisions. The introduction of high speed, air breathing turboprop and turbojet aircraft into air commerce made bird strikes and bird ingestion by jet engines a global flying safety problem. Concern over this condition is shared by military pilots, commercial pilots, and passengers. As aircraft speeds increase and airports become more numerous and busier, the problem increases in extent and complexity. It was apparent by 1960 that the problem would grow worse and that work should be directed toward reducing the number of incidents.

In 1960 an Electra aircraft striking starlings crashed at Boston, killing 61 passengers. In November 1962, a Viscount aircraft crashed with a loss of 17 lives, after a collision with two whistling swans between Baltimore and Washington. These accidents focused attention on the bird-hazard problem in the United States.

For the Air Force the result is more than an inventory of damaged planes, since collisions bring death or injuries to air crew members. The estimated cost figure of more than $10 million annually covers only the man-hour repair expenses, materials used, and replacement of badly damaged engines. No attempt is made to put a dollar value on the loss of lives, the value of fuel jettisoned prior to emergency landings, the absence from duty of the injured, or the price of an aborted mission. Hence the figure of more than $10 million a year admittedly falls short of being realistic.

Statistics are blunt; the past dozen years have seen an increase of more than tenfold in such accidents which result in significant damage to Air Force planes. To obtain data on the frequency of bird strikes, the Directorate of Aerospace Safety ordered in 1965 the reporting of all bird strikes during that year, regardless of damage caused. The number of collisions reported was 839, with plane damage occurring in 279 of the cases. A report has been published each year since 1966. During the first 6 months of 1969, 168 Air Force losses due to bird strikes were reported.

As long as base aircraft were powered with the old reciprocating engines, neighborhood birds rarely posed any particular problem. Engine noise probably preceded the plane, alerting birds to take evasive action. A plane's comparatively slow closing-speed gave them time to get out of the way. Whirling props usually served well to protect windscreens and canopies.

The advent of jets drastically changed this picture. Sound trailed aircraft, eliminating advance warning for evasion. Closing-speed multiplied. Engines sucked quantities of air—and any flying creature in that air. Until the 1962 Viscount crash in which a whistling swan struck the horizontal stabilizer, windscreens were considered the only part of an aircraft susceptible to catastrophic bird impact damage. Subsequent investigation suggested that the safety of aircraft cannot be directly correlated with the aircraft parts receiving the maximum number of strikes. For example, the horizontal stabilizer, which receives less than 4 percent of total strikes, was responsible for the Viscount crash.

The problem existing at subsonic speeds is magnified at supersonic speeds. Figure 1 shows what happened when a 2- to 3-ounce horned lark struck an X-15 rocket sled at Mach 1.5 at Holloman AFB. Flight engineers believe that at multiple Mach speeds a large bird striking a supersonic transport could cause the aircraft to disintegrate. A T-37 jet trainer collided with a turkey buzzard at Moody AFB. The windscreen hit the buzzard while the pilot was practicing touch and go landings. Canadian research shows that birds, even large birds, liquefy when they strike the angular surface of a windscreen at high speeds.

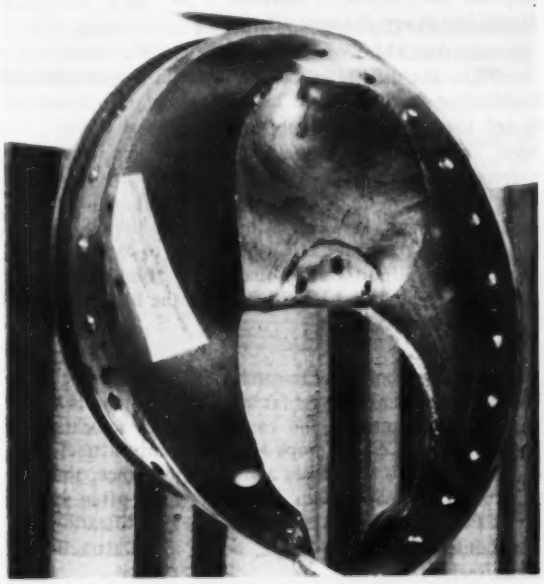

Figure 1. Plate struck by a 2- to 3-ounce horned lark. Speed was Mach 1.5 on the X-15 rocket sled at Holloman AFB.

*From a presentation before the Biological and Medical Sciences Subcommittee, Defense Committee on Research, The Pentagon, 16 October 1969.

A Canadian Pacific Airlines Boeing 737 was severely damaged because the pilot was brought into a descending approach to Toronto from Winnipeg without being advised to reduce airspeed or to be alert for many geese. The birds were on the radar screen, but were unrecognized as such by the air traffic controller.

In the USSR, on the average, more than 1,500 bird strikes to civil aviation are reported to occur annually. On the basis of these reports, it is established that the number of bird strikes for the past 6 years has increased by 6 times. About 66 percent of the bird strikes are reported at 150-300 km.p.h. About 90 percent of the incidents occurred at about 2,000 feet in altitude. About 68 percent of the accidents happen on or near the airfields. Damage to the engines occurs in about 44 percent of the bird strikes and to the windscreen in about 13 percent of the strikes.

The high incidence of bird strikes to aircraft showed the need for unequivocal methods in determining whether or not engine failure was due to the ingestion of a bird. However, no programs will quickly reduce the bird strike problem to negligible proportions unless we can manage a research "break through". Initially, because the problem was considered to be partly of an engineering nature, studies were undertaken to determine the strength of aircraft components necessary to resist bird impact without serious damage. It soon became apparent that the weights of birds and the speeds of aircraft would permit only limited improvement through engineering. A bird-proof aircraft would involve unacceptable structural weight. No way has been found to birdproof a jet engine without a drastic loss in aerodynamic efficiency.

When the difficulties of dealing with the problem by engineering methods were realized, major effort was directed toward biological solutions. Biological research has been conducted at several U.S. Air Force bases and universities to learn about the bird species involved, why they were present on or near bases, and what could be done to disperse them. However, a proposal to the USAF Civil Engineering Laboratory at Kirtland AFB to explore means to improve airport safety has been stymied, due to reduction of budgeted FY 70 funds in the bird strike area from $50,000 to $10,000.

Base area ecological research determines the cause of bird presence at a base. As far as possible, attempts should be made to eliminate the cause, such as relocation of garbage areas. Certain crops are particularly attractive to certain birds. To give bases a smart appearance, they are sometimes landscaped with shrubbery which often attracts birds. Ponds and pools put in for base beautification may also contribute to the danger, acting as an attraction to waterfowl.

In addition to modification of habitat, many means of dealing with emergent bird problems have been explored. These have included pyrotechnics, trained falcons, and recorded distress and alarm cries. Experiments with shotgun-like noises and other disturbing sounds have caused certain birds to move elsewhere. But what bothers one branch of a particular bird family does not always disturb members of another branch. Frequently the most useful device is a reliable hired gun. The manager of LaGuardia Airport reported that his most effective control is a roving marksman with a shotgun, because the gulls become so accustomed to carbide cannons that they rise only 6 inches off the barrel upon firing and then re-alight.

There is also the problem caused by birds encountered in flight *away* from bases. Known bird contacts with aircraft have occurred up to altitudes of 21,000 feet; however, the bulk of bird movement on migration takes place below 10,000 feet.

Since 1963 radar has been used in the U.S. to study bird migration. Plan position radar, as used for air traffic control, provides clear images of birds, although attempts have been made to engineer the bird out of the picture. The radarscope image is photographed with a motion picture camera on a 10-second time-lapse basis. The resulting films, projected at normal speeds, provide a speedup of 240 times, which permits a 24-hour radar watch of 150-mile circles to be reviewed in a few minutes.

AFOSR is devoting a few studies to the major migratory movements of large birds capable of causing serious damage to aircraft in flight. Information from radar gives us a rather clear picture of the sort of hazard that exists for limited times at specific points during migration.

Additional AFOSR supported research (Dr. Warren Flock, University of Colorado) showed the feasibility of monitoring migratory bird movements over a wide area, using radar at a small number of FAA centers. Data from this research showed that more extended waterfowl surveillance programs are needed to define waterfowl migration corridors more accurately and to predict the probability of collisions between birds and aircraft.

Though complex, the broad ecological approach to the problem seems now to be the only usable one to combat the problem. Its complexity almost creates an atmosphere of futility. Only a small airborne piece of equipment—one that might function as an automated radar-controlled device capable of causing flying vertebrates to move or fall from the flight path of the aircraft—might solve the problem.

The reported effects of microwaves on birds also suggested the possibility of using microwaves to alleviate

the bird hazard problem. Research, described in detail by Dr. J. A. Tanner of the National Research Council of Canada, defines the escape reaction of a bird placed in a microwave beam. To exploit the possibilities of microwave interaction, a machine was built to study bird behavior and to determine the importance of the microwave field parameters. The machine, which Dr. Tanner calls *Carousel,* accommodates 50 birds and is automated to record on film and video tape the behavior of each bird during the experiments. The muscles of the wings and legs are profoundly affected. The pattern of activity consists of a depression in the level of electrical activity in the muscles on the side of the bird away from the center of the field, accompanied by a substantial increase in the frequency of the electrical activity on the contralateral side. Primary mechanisms have yet to be identified.

Moody AFB, Georgia, is near a forested swamp that is the roost of an estimated 3 million red-winged blackbirds. Mornings and evenings they cross runways and approaches, disrupting flight schedules. In an attempt to provide some relief for this disruptive and dangerous problem, research demonstrated that certain sound components of the T-37 jet engine caused an actual physical repulsion of red-winged blackbirds. When these components were extracted, condensed, magnified, and directed at the hundreds of thousands of blackbirds that fly across the base, it was found that these enormous flocks could be deflected up to 90 degrees in flight path.

In 1968, the USAF Air Training Command Surgeon's Office requested the assistance of the Air Force Office of Scientific Research in a flight safety problem at Randolph AFB, Texas. The Command Veterinarian, Colonel William D. Nettles, suggested bats as the cause. Bats were shown to constitute a significant hazard to jet aircraft at Randolph by the AFOSR grantee, Dr. Timothy Williams of Rockefeller University. It was suggested that the dense concentrations of bats leaving and returning to the large caves in the morning and evening hours might be successfully avoided. The FAA at San Antonio International Airport had believed that these radar presentations were "thermal inversions" until they were shown to be clouds of millions of bats.

Microscopic methods and the use of amino-acid analysis of protein residues have been described by Dr. LaHam of the University of Ottawa, Canada, as the means of establishing whether a bird has been involved in an engine failure. Before launching an expensive and drawn out reconstruction investigation, any chemist with access to an amino-acid analyzer can determine, at little cost and in very little time, whether bird ingestion was involved in a crash.

Some modest support of biological studies has been extended by the FAA. Tests and movies have been made of bird-impact resistance of wind-screens, airframes, and ingestion in turboprop and turbojet aircraft. To further the recognition of the bird-hazard problem and to encourage a coordinated effort, the Administrator of the FAA established an Inter-Agency Bird-Hazard Committee composed of representatives from the armed forces and other interested departments and agencies. This Committee's stated function is to exchange research reports, prepare advisory data, and make recommendations to the Air Force and the aviation public. The Committee, which is without funds to support research, is largely guided by FAA.

Prior to the United States crashes in 1960 and 1962, the Canadians had been working on the bird strike problem. In 1963 the Canadian National Research Council set up the Associate Committee on Bird Hazards to Aircraft to study the problem and to recommend solutions.

In addition to the work in the United States and Canada, studies have been done in northern Europe at NATO bases, using the radar facilities of a number of countries.

The global concern for the problems was demonstrated in September 1969 by an urgent First World Conference on Bird Hazards to Aircraft, held in Ontario at Queens University.

With the arrival of the next phase of the Automated Air Traffic Control System, of the jumbo jet, and of air densities far exceeding today's, only the location of the next crash and its accompanying fatalities remains in doubt. The coming Automated Air Traffic Control System may be predicated on a radar-controlled computerized scanning system.

Horizontal Flow Of Materials In Solar Granules

SACRAMENTO PEAK OBSERVATORY, AFCRL

The face of the quiet sun has a granular structure—like rice in a bowl. Over the total surface there may be four million individual cells or granules with diameters of about 100 km and average lifetimes of about 10 minutes. Each cell represents the upward welling of material from beneath the visible surface. Solar physicists can measure the velocity of this upwelling material fairly directly by Doppler methods; these measurements show the maximum upflow at the granule center to be about 400 meters a second.

An outward horizontal flow of material from each granule center is assumed simply because this is the normal behavior for convective liquids when they reach some upper boundary. Measurement of this horizontal flow is not easy. Such measurements have been reported for the first time by J.M. Beckers of AFCRL's Sacramento Peak Observatory, Sunspot, N.M., and R.A. Morrison of the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. The study, reported in a recent paper submitted to *Solar Physics*, states that the maximum horizontal flow, which occurs at about 500 km from the granule center, is about 250 meters per second.

For their studies, Beckers and Morrison used the 30 cm coelostat telescope at Sacramento Peak. The key to the measurements of horizontal flow is to obtain Doppler velocity data—which is not possible at points near the center of the solar disk, but is possible at regions toward the solar limb. Although tricky, Beckers worked out a method using high-resolution filtergrams. The solar image is photographed in the opposite sides or wings of the 6569.2 angstrom line. The resultant filtergrams from each side of the line have different contrasts, and Doppler velocities can be derived from these contrast differences.

Because the contrasts are slight at best, in order to detect intensity differences, the astronomers had to make about 1.5 million intensity measurements—a half million in each of three solar regions selected for study. The intensity and Doppler data for about 1100 granules, chosen for analysis in each of the three regions, were averaged. Although the statistical averaging process lost the properties of the individual granules, it removed the uncertainties in the data derived on individual granules.

Some of the findings follow: From a zero horizontal velocity at the center of the granule, the flow increases radially outward to a maximum velocity of about 250 meters a second at a distance of 500 km. At 1000 km from the center, the velocity has decreased to about 50 meters a second. A slight reverse flow occurs at 1500 km. Beckers and Morrison found no evidence of a vortex movement in the outward flow. At the periphery of the granule, there is a moderate downwelling of material.

In a search for differences between granules of different brightness, Beckers and Morrison divided the granules into two groups, according to their brightness. The weaker granules, which are generally smaller than the bright ones, have a smaller upflow. The outflow, however, is of comparable strength for the two sizes. In general, the horizontal outflow is much larger than had been suspected.

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Readers Interchange

(To be resumed in the November-December issue)

It is hoped that the Readers Interchange, particularly under the column headed "Speculative Ideas," will encourage reader participation in suggesting further investigations that will lead to new product development. Further reader participation is possible through the publication in a subsequent issue (with the permission of the reader) of the answers to question 2 of the tear-out page, "Comments to the Editor," in which applications are suggested for the research described in any article of this issue.

Columns headed "Research Advances" and "Research Needs" which contain materials furnished by DOL research and development laboratories, and the column headed "Invention Disclosures" which contains abstracts selected from invention disclosures (originally submitted for possible patent applications, but now released from such action*) may suggest further research for our readers.

Reports of actions stimulated by the Readers Interchange or suggestions for its improvement are welcome.

Director of Laboratories, AFSC/DL
Technical Information Division/DLLT/REVIEW
Andrews Air Force Base, Washington, D.C. 20331

**For a more detailed discussion, see "Project: Use It" by Lt Col Ludwig Lippert, Staff Judge Advocate, in the OAR Research Review, Vol IX, No. 3, May-June 1970.*

Request for further information from institutions and individuals may be either mailed to the addresses below, or telephoned to the individuals named as "Contact" at the end of each article. If no organization follows the name of the contact, assume that it is the same organization given under the title of the article.

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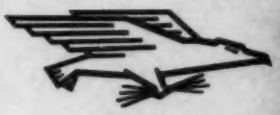

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